Constraining ME Flux
Using ν + e Elastic Scattering

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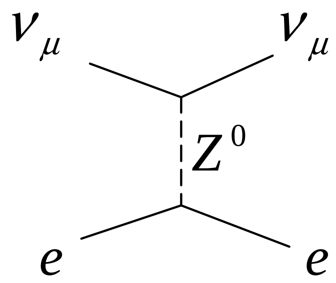
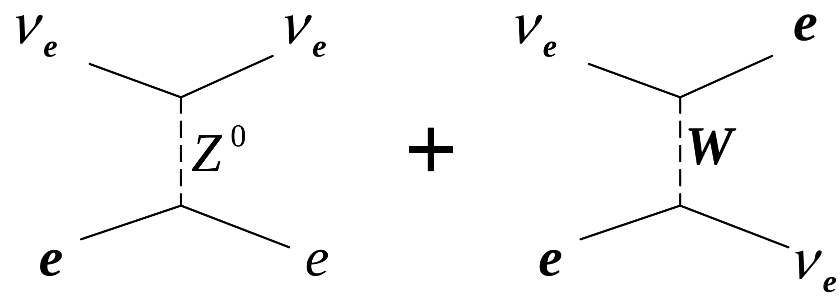
Constraining flux using $\nu_\mu + e$ scattering





$$\nu_\mu + e^- \rightarrow \nu_\mu + e^- \qquad \nu_e + e^- \rightarrow \nu_e + e^-$$

$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^- \qquad \bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$

- ν + e scattering is pure leptonic process and theoretically well understood (~1% precision)
- ν scattering on light electron means small center of mass energy, consequently it has tiny cross section (~1/2000 compare to νN scattering)
- Scattering on light electron also means very small Q^2, which produces very forward electron final state
- In principle, if we measure event rate of this process, we can determine flux (R = Φσ)
- But it's not that simple because cross section(σ) and flux(Φ) are function of neutrino energy
- And we only measure electron energy
  - Because electron angle is really all forward within detector resolution, we don't have sensitivity to calculate neutrino energy using 2 body kinematics

Signal and Background Processes

All can look like single electron final state

$$\nu_\mu + e \to \nu_\mu + e$$
$$\bar{\nu}_\mu + e \to \bar{\nu}_\mu + e$$

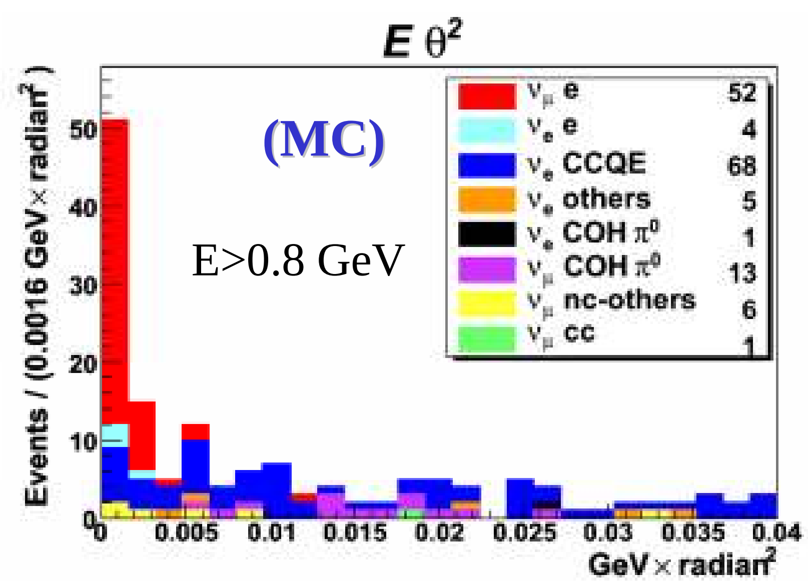
It produces a very forward electron
It can be separated from background using ***Eθ***^{2}

$$\nu_e n \to e^- p$$
$$\bar{\nu}_e p \to e^+ n$$

Check vertex activity to reject

$$\nu_\mu A \to \nu_\mu A \pi^0$$

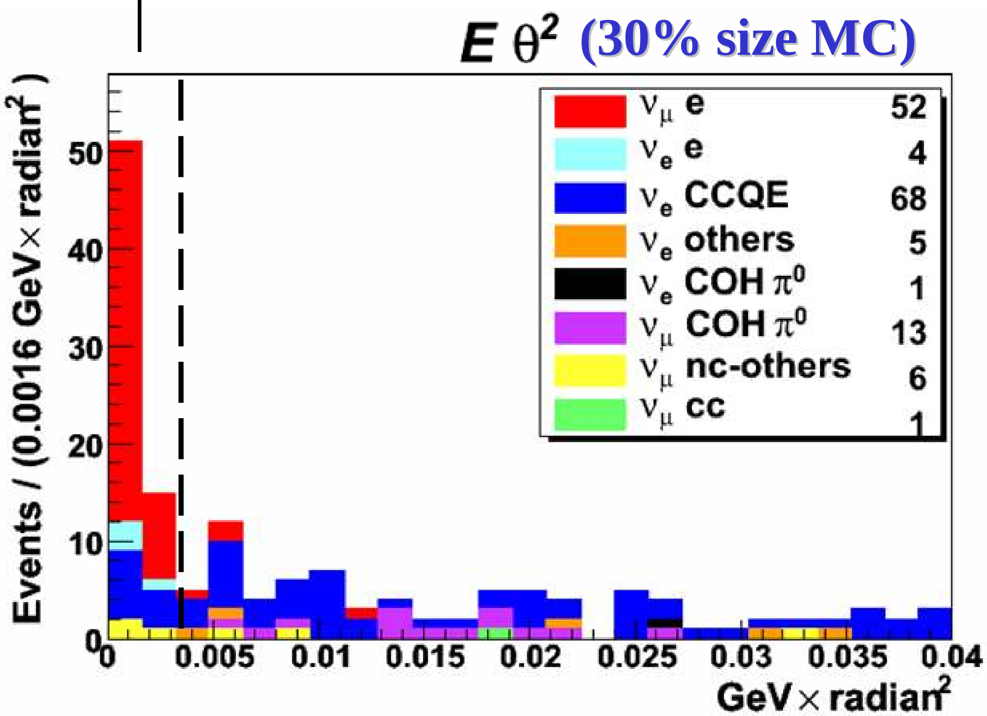
1. Only one of two gammas is detected
   − dE/dx at the beginning is different from electron
2. High energy π^0 decays into two gammas with very small opening angle
   − Check transverse energy distribution



E: Energy of electron candidate
θ: Theta of electron candidates w.r.t. beam direction

Signal Events

First two bins are signal rich



	All bins	1st two bins
ν_μ e	52	48
ν_e e	4	4
ν_e CCQE	68	11
ν_e others	5	0
ν_e COH π^0	1	0
ν_μ COH π^0	13	0
ν_μ nc-others	6	3
ν_μ cc	1	0
Total	150	66

52 signal

14 background

- Low energy beam, forward horn current
- Number of $\nu\ e$ scattering ($\nu_\mu\ e$ and $\nu_e\ e$) events in this 30% MC: 52 ± 9
  - 17% statistical error
- The projected sample will have ~3 times signal/background (173/47).
- That measurement would produce a statistical uncertainty of 8.6%
- What does it mean?
  - It means that it provides a single constraint number about the whole flux

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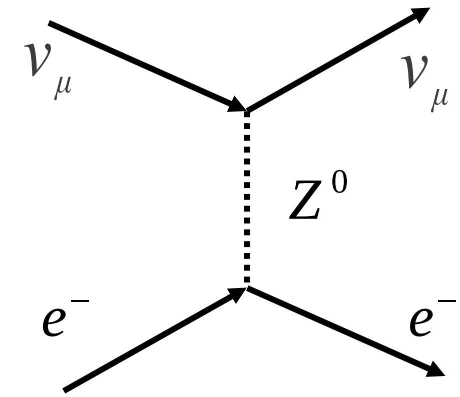
Constraining ME flux using e-ν

$$\frac{dN(T)}{dT}=\int dE_{\nu}\frac{d\Phi(E_{\nu})}{dE_{\nu}}\frac{d\sigma(T,E_{\nu})}{dT}$$

$$\text{¿}= Acceptance\times\sum_{j}\frac{d\Phi_{j}(E_{\nu})}{dE_{\nu}}\Delta E_{\nu j}\times\frac{d\sigma(T,E_{\nu j})}{dT}$$

$$\nu_{\mu}+e^{-}\rightarrow\nu_{\mu}+e^{-}$$



For $\nu_l e\rightarrow\nu_l e$, the differential

Cross-section (to the 1% precision):

$$\frac{d\sigma}{dT}=\frac{2G_{\mu}^{2}m_{e}}{\pi E_{\nu}^{2}}[a^{2}E_{\nu}^{2}+b^{2}(E_{\nu}-T)^{2}-ab\,m_{e}T]$$

General Idea (simulation work)

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SM a and b parameter, here $s^2 = \sin^2\theta_W \approx 0.23149 \pm 0.00015$

weak mixing angle: θ_W ; Fermi constant $G_\mu = 1.16637(1) \times 10^{-5} Gev^{-2}$

factor $\frac{2G_\mu^2 m_e}{\pi} = 1.5 \times 10^{-41} GeV^{-1} cm^2$

Event rate for every T value (Electron Kinetic Energy Distribution)

$$\frac{dN(T)}{dT} = \int dE_\nu \frac{d\Phi(E_\nu)}{dE_\nu} \frac{d\sigma(T, E_\nu)}{dT}$$

$$¿= Acceptance \times \sum_j \frac{d\Phi_j(E_\nu)}{dE_\nu} \Delta E_{\nu j} \times \boxed{\frac{d\sigma(T, E_{\nu j})}{dT}}$$

For j th Flux(Ev) bin, (for a certain Ev value) the electron kinetic energy T spectrum

θ

T, vertex x, y, z, dependent

Adjusting the Flux; (To re-weight the flux To get the smallest χ^2)

$\frac{dN_{detected}(T)}{dT}$ and $\frac{dN_{predicted}(T)}{dT}$

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Work did

- Absolute event rate from theory (Calculation of Electron available in the Fiducial Region)
- Event rate from Genie MC (higher statistics than LE)
- Predicted Electron Energy Spectrum
- Test of the sensitivity of electron kinetic energy distribution to the re-weighted flux

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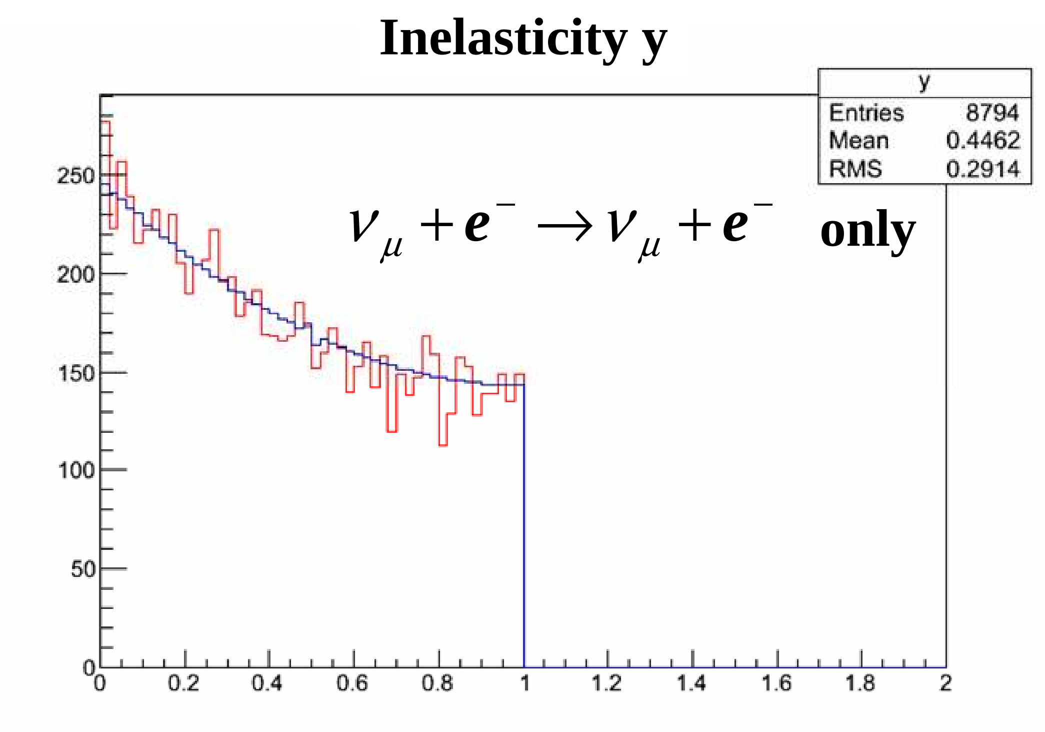
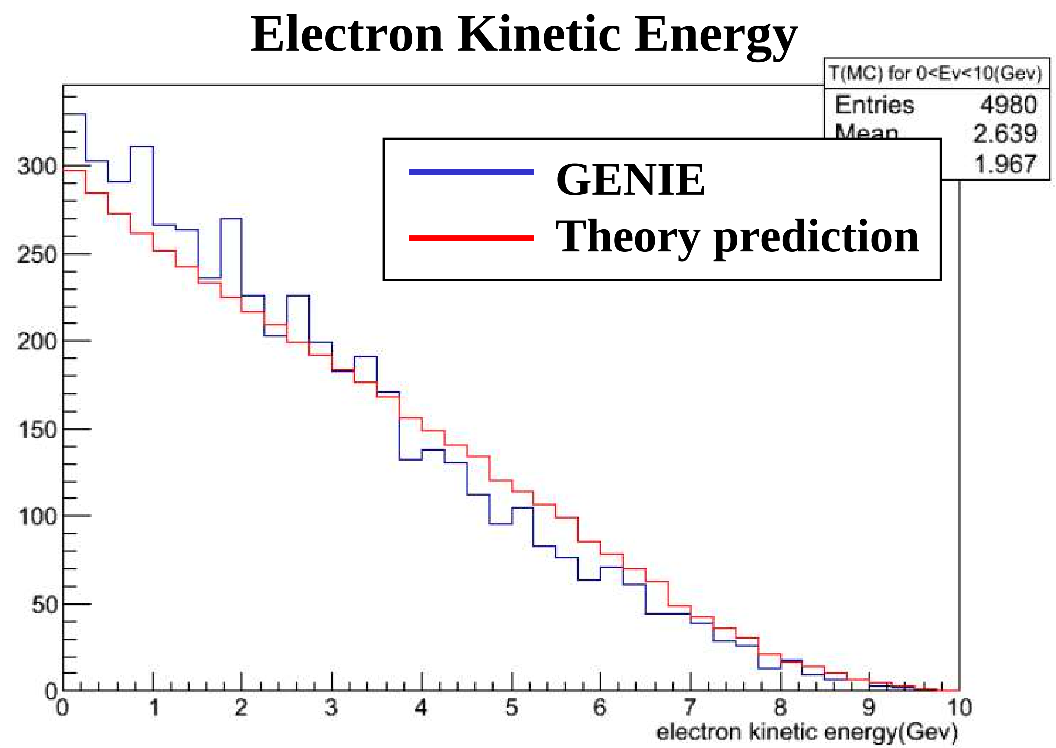
Electron Energy Spectrum Prediction





- Compare GENIE MC sample with prediction
- Inelasticity is consistent with theory
- Electron kinetic energy has some shape difference but couldn’t figure out the issue

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Next Steps

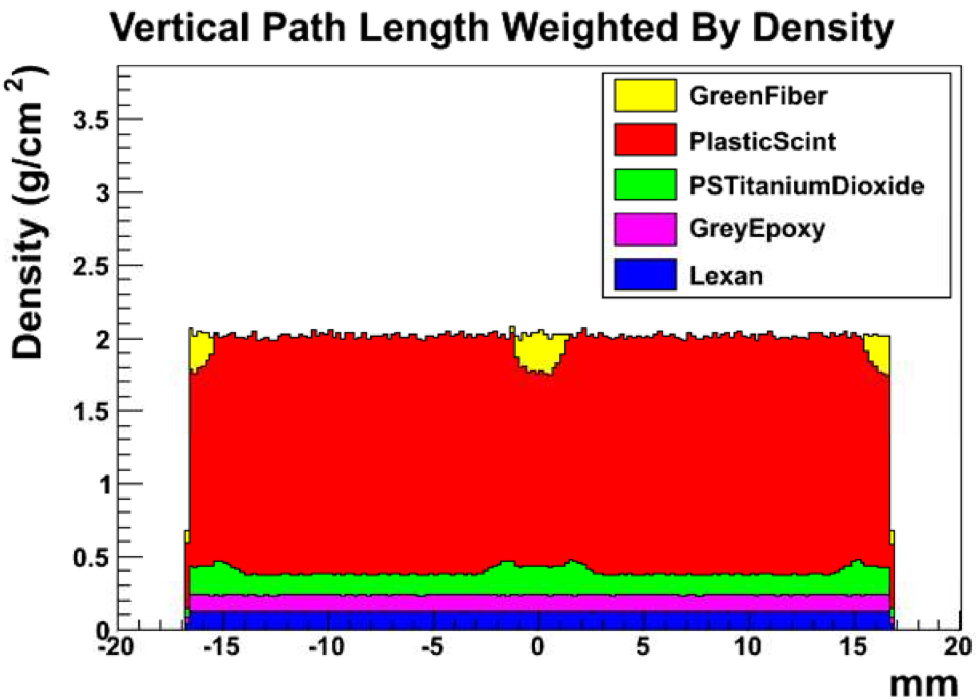
- Determine the reconstructed electron energy distribution from MC (electron shower reconstruction)

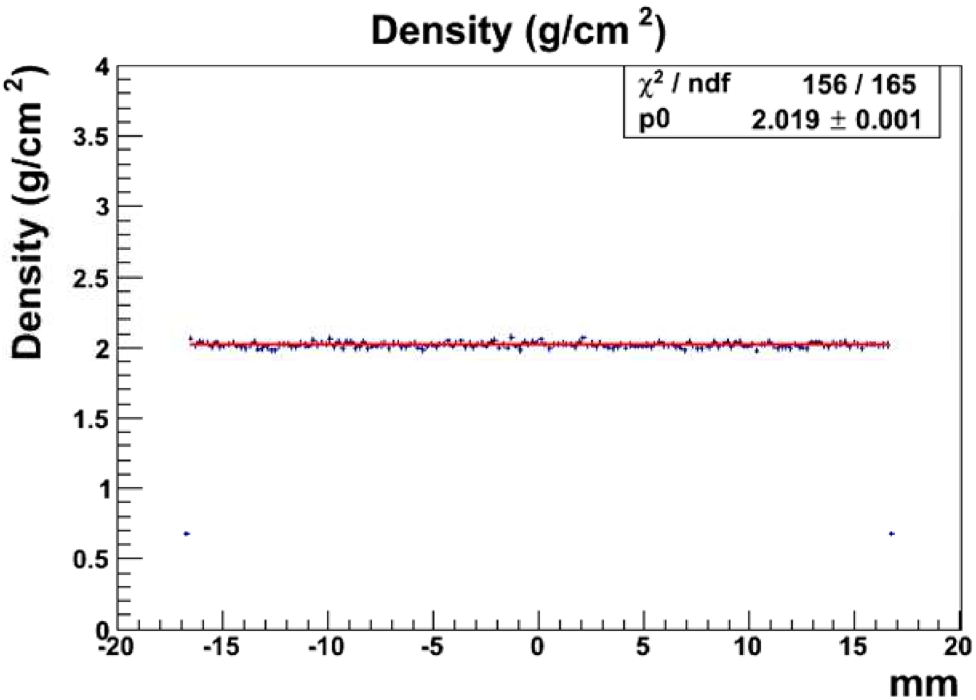
- KE distribution from Genie $\longrightarrow$ Flux (with uncertainty)

Fiducial Mass

- Module: 25~80 (112 planes)
- Apothem: 88.125cm
- Hexagon area = $2\sqrt{3}\times \text{apothem}^2$ = 26902 cm^2
- Plane density from geometry scan = 2.019 g/cm^2
- Plane mass = density $\times$ area = 2.019 g/cm^2 $\times$ 26902 cm^2 = 54315g
- This plane mass is based on geometry definition
  - It can be slightly differently from reality
  - But event rate prediction using geometry definition should be able to reproduce MC event size

Mass Fraction (Rectangular Scan)

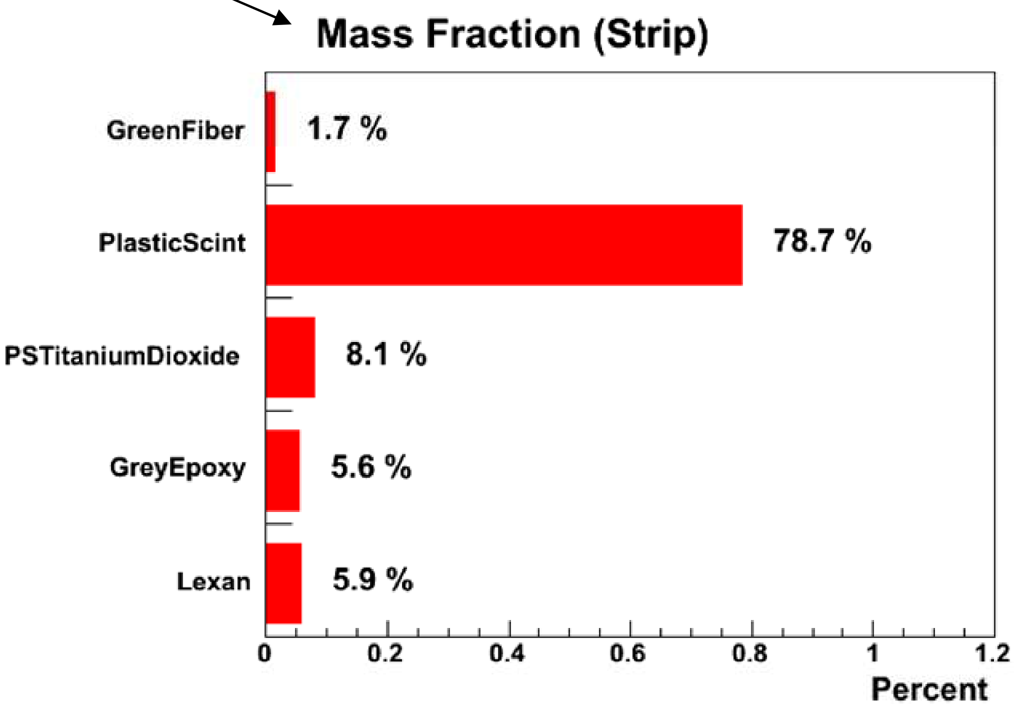




- Plane density = 2.019 g/cm^2

Element mass fraction

From material scan from previous slide



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Material name	Element	Element mass fraction
PlasticScint	H	0.09
	C	0.92
PSTitaniumDioxide	H	0.07
	C	0.78
	Ti	0.09
	O	0.06
GreenFiber	H	0.08
	C	0.92
GreyEpoxy	C	0.55
	H	0.09
	Cl	0.09
	O	0.21
	Al	0.03
	Si	0.03
Lexan	H	0.06
	C	0.76
	O	0.19

=

Element	Mass fraction
C	0.874
H	0.082
O	0.028
Ti	0.007
Cl	0.005
Si	0.002
Al	0.002

- Combined volume fraction with elements composition to calculate element mass fraction

Number of electrons per plane (with fiducial hex cut)

Mass fraction × plane mass

From previous slide

Element	Mass fraction	Mass (g)	Atomic number	Mol density (g/mol)	Moles	Number of electrons (moles)
C	0.874	47479.7	6	12.011	3953.0	23718
H	0.082	4465.1	1	1.008	4429.7	4430
O	0.028	1502.7	8	15.999	93.9	751
Ti	0.007	395.3	22	47.867	8.3	182
Cl	0.005	276.3	17	35.45	7.8	133
Si	0.002	99.6	14	28.085	3.5	50
Al	0.002	95.7	13	26.982	3.5	46
					total	29309

- Number of electrons per plane with fiducial cut = 29309 moles
- Electrons in fiducial volume = 112 planes $\times$ 29309 moles = 3,282,608 moles = 3.28×10^6 moles electrons
- $3.28\times10^6 \times 6.022 \times10^{23} = 1.9768 \times10^{30}$ electrons in fiducial volume

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How Many Electrons Available In The Fiducial Region?

Composition for plane

(including stripes, epoxy, tape, and skins)

C 87.62%

H 7.42%

O 3.18%

Ti 0.69%

Al 0.26%

Si 0.27%

Cl 0.55%

Areal Mass: 20.24 kg/m2

Estimated uncertainty (1 sigma)

0.028 g/cm2 (1.4%).

(Document #: MINERvA-doc-6016-v7)

Fiducial volume:

module 25~80 （112planes）

cross section: apothem=88.125cm

Hexagon Area: 2.69 m2

20.24*2.62=54.45 kg/plane

Electron available:

$$1.96715\times10^{30}$$

Ready to calculate the absolute number of events

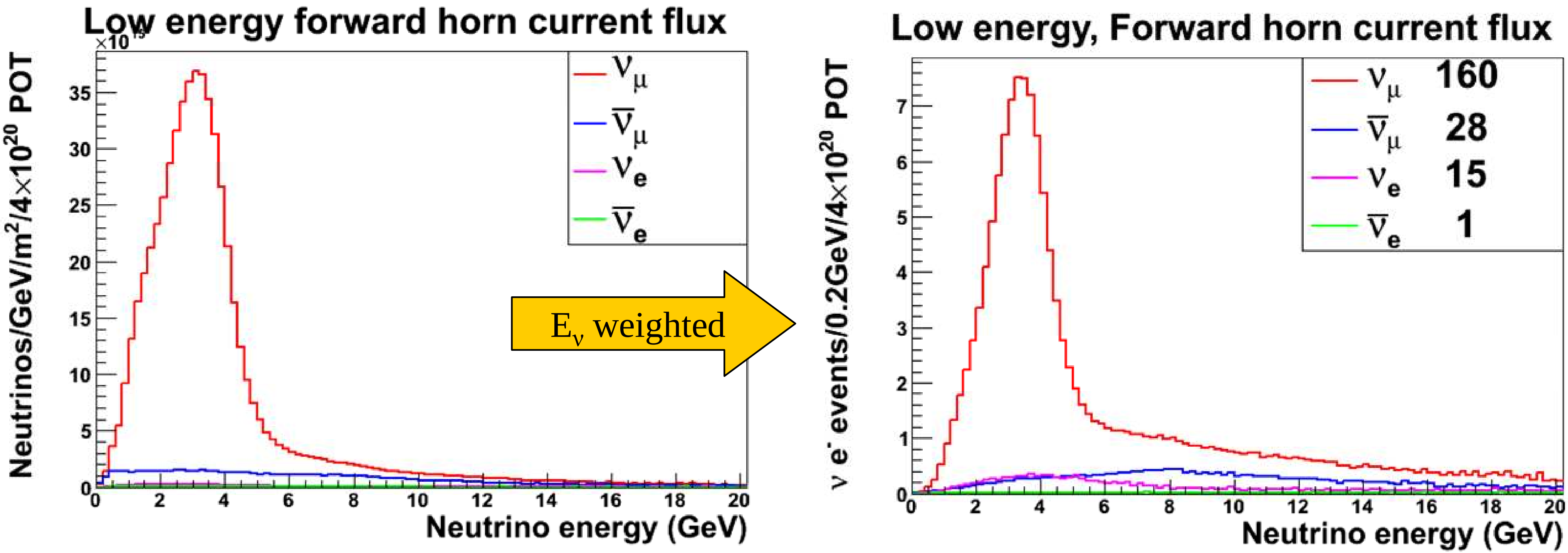
Wenting vs Jaewon

Element	Mass fraction (Wenting)	Mass fraction (Jaewon)
C	87.62	87.42
H	7.42	8.22
O	3.18	2.77
Ti	0.69	0.73
Cl	0.55	0.51
Si	0.27	0.18
Al	0.26	0.18

	Wenting	Jaewon	W/J ratio
Plane density (g/cm2)	2.024	2.019	1.0025
Fiducial mass (kg)	6098	6083	1.0025
Total electrons in fiducial	1.97E+30	1.98E+30	0.9949

- Wenting mass calculation based on measured material budget
- Geometry has more hydrogen than reality
- Higher hydrogen fraction makes my number of electron higher
- Wenting’s and my calculations on total number of electrons in fiducial volume have only 0.5% difference

Total Cross Section

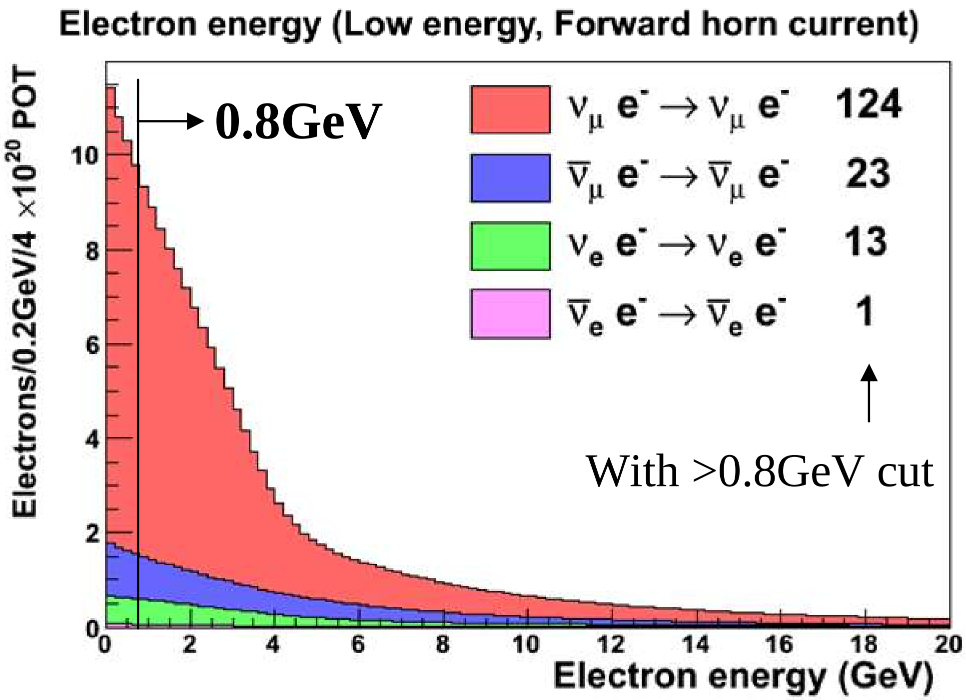


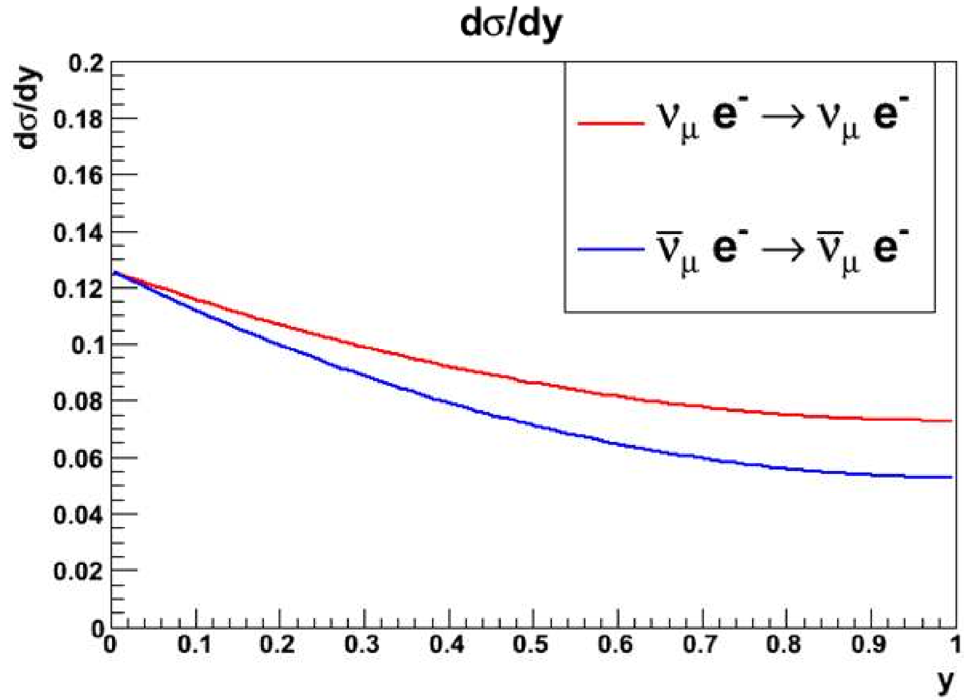
$$\sigma(\nu_\mu e^-) = \frac{G_F^{\;2} s}{\pi}\left[\left(-\frac{1}{2}+\sin^2\theta_W\right)^2+\frac{1}{3}\sin^4\theta_W\right] \quad \propto E_\nu$$

$$s = 2m_e E_\nu$$

- Total cross section is proportional to beam energy
- High energy tail contribution gets bigger

Electron Energy Spectrum

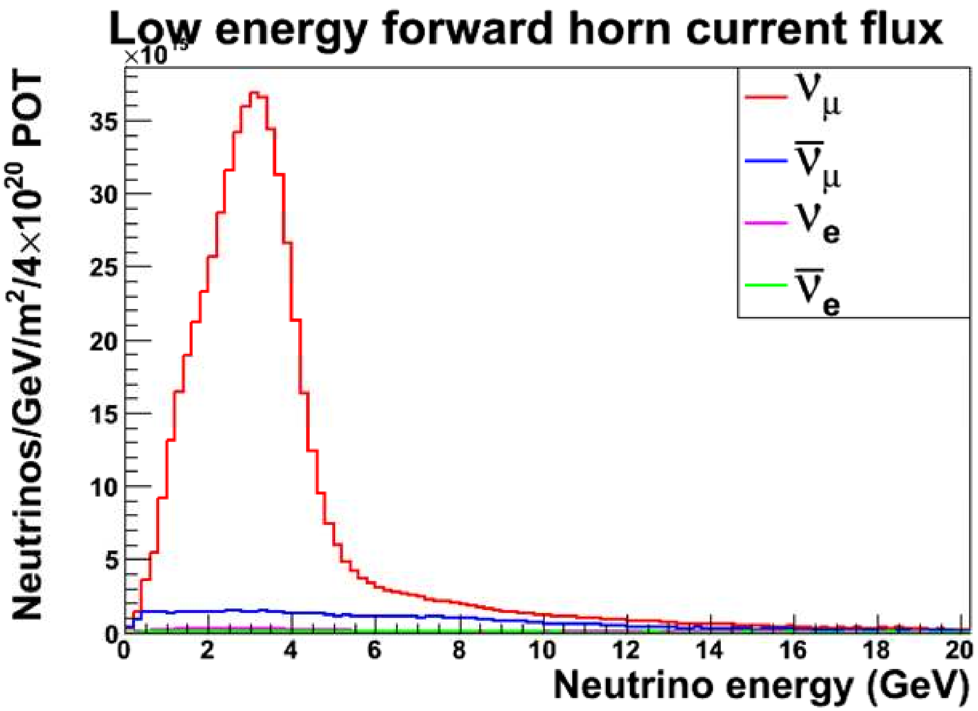


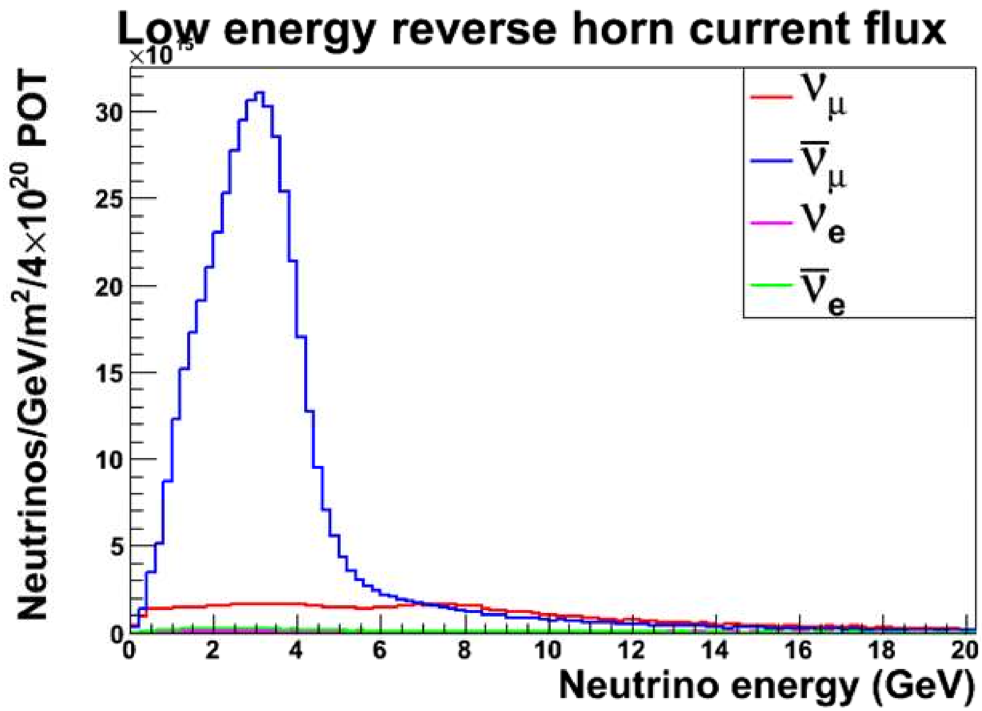


$$\frac{d\sigma(\nu_\mu e^- \to \nu_\mu e^-)}{dy} = \frac{G_F{}^2 m_e E_\nu}{2\pi}\left[\left(\frac{1}{2} - \sin^2\theta_W\right)^2 + \sin^4\theta_W (1-y)^2\right] \qquad y = \frac{\text{(electron KE)}}{\text{(neutrino energy)}}$$

- High energy electron from high energy neutrino
- Low energy electron from both low and high energy neutrino
- Note also anti muon neutrino and electron neutrino contribution

Flux


Low energy forward horn current flux
×10^15
Neutrinos/GeV/m^2/4×10^20 POT
Neutrino energy (GeV)
ν_μ
ν̄_μ
ν_e
ν̄_e


Low energy reverse horn current flux
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Neutrino energy (GeV)
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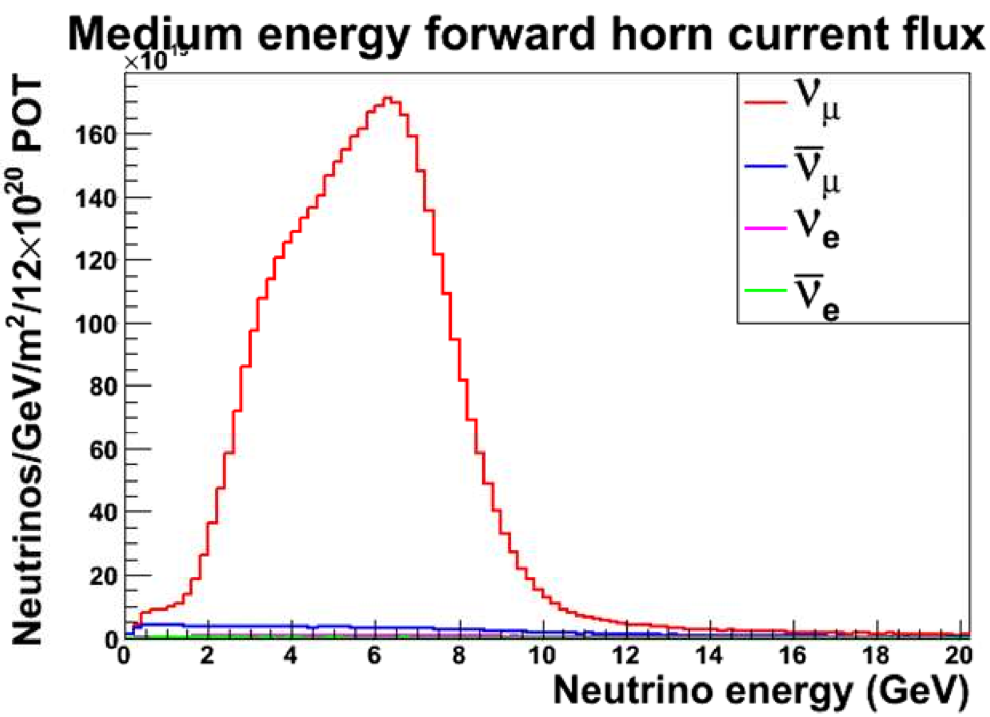
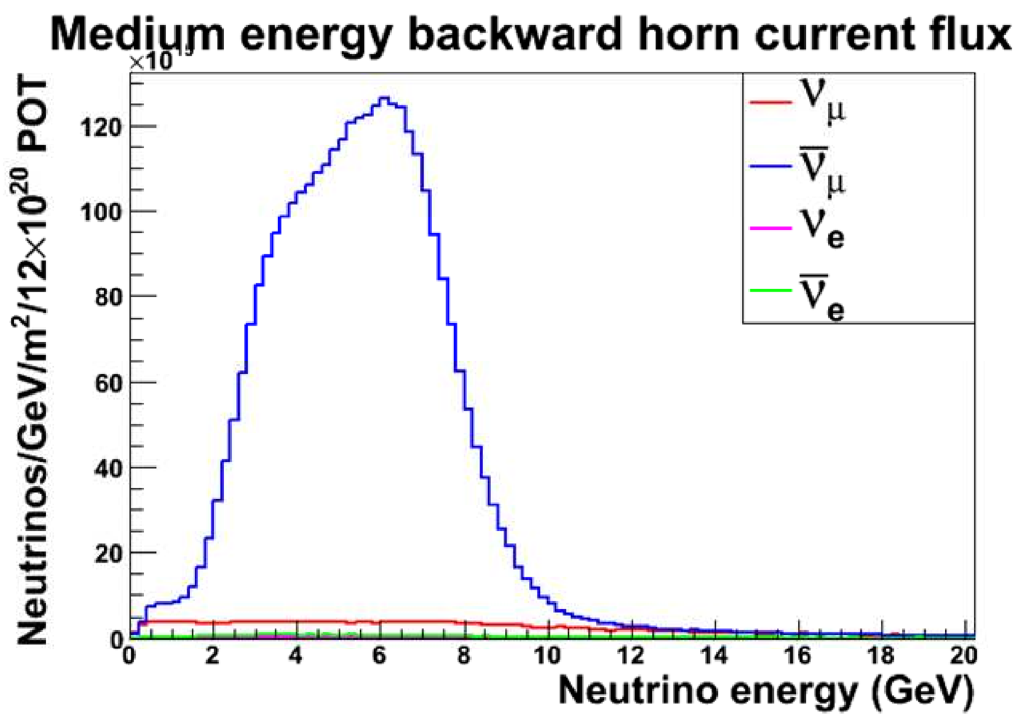
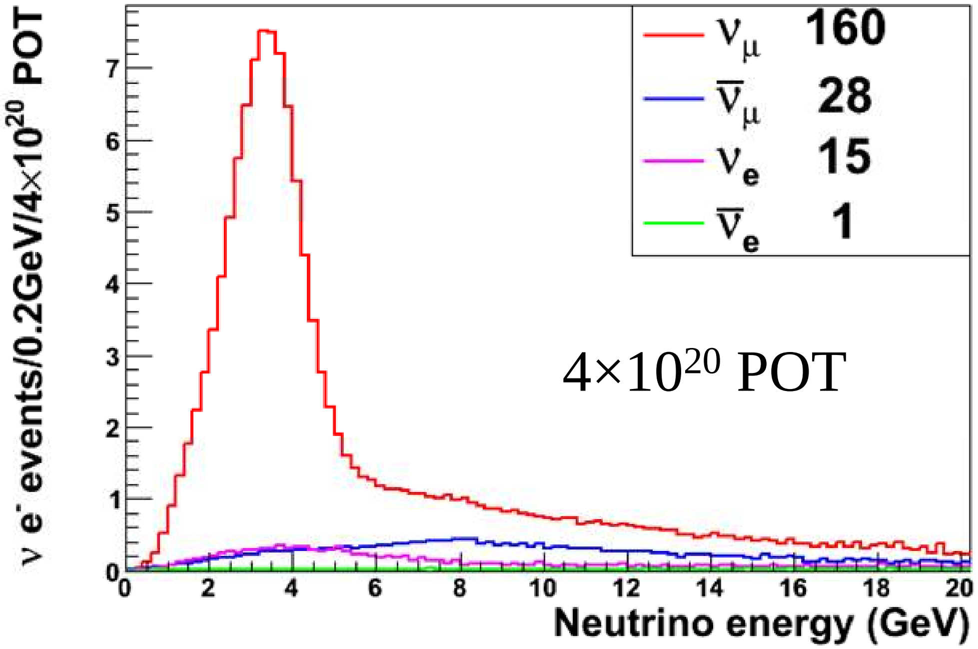

Medium energy forward horn current flux
×10^15
Neutrinos/GeV/m^2/12×10^20 POT
Neutrino energy (GeV)
ν_μ
ν̄_μ
ν_e
ν̄_e

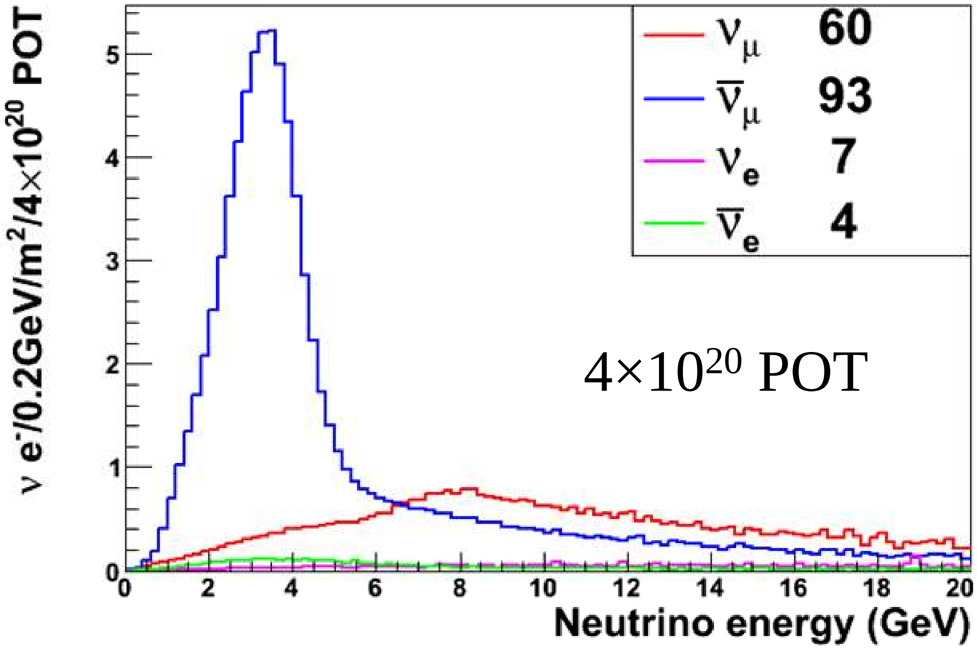

Medium energy backward horn current flux
×10^15
Neutrinos/GeV/m^2/12×10^20 POT
Neutrino energy (GeV)
ν_μ
ν̄_μ
ν_e
ν̄_e

Neutrino Electron Scattering Event rate

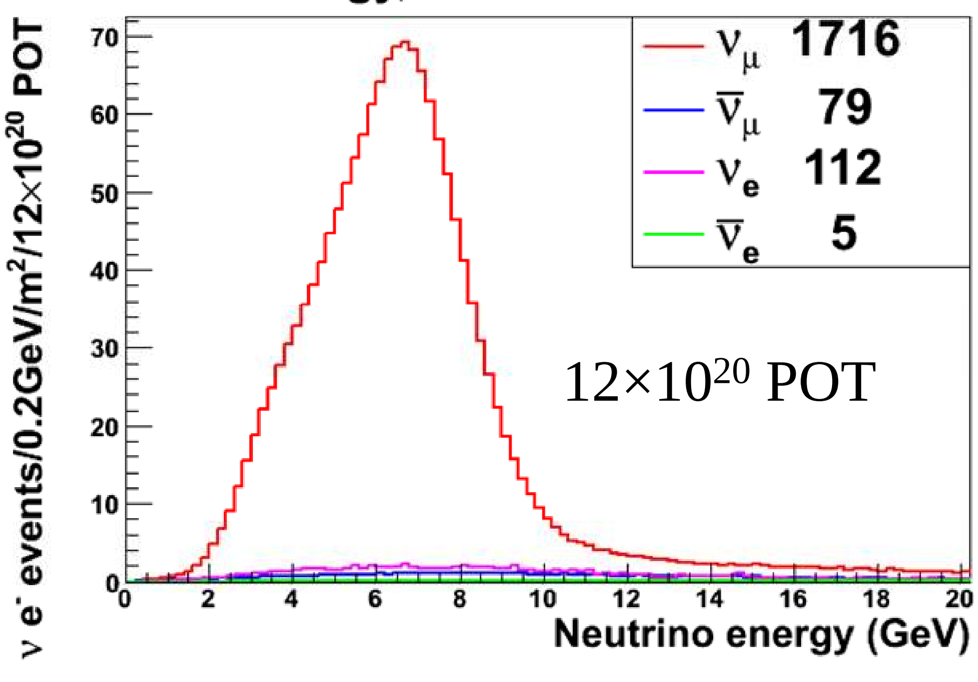
Low energy, Forward horn current flux



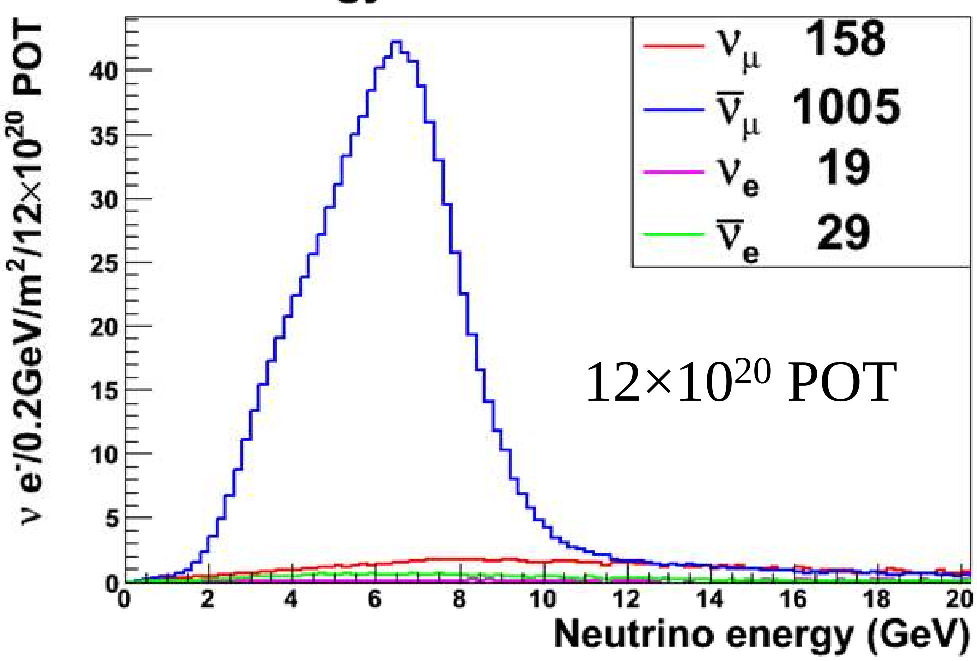
Low energy reverse horn current flux



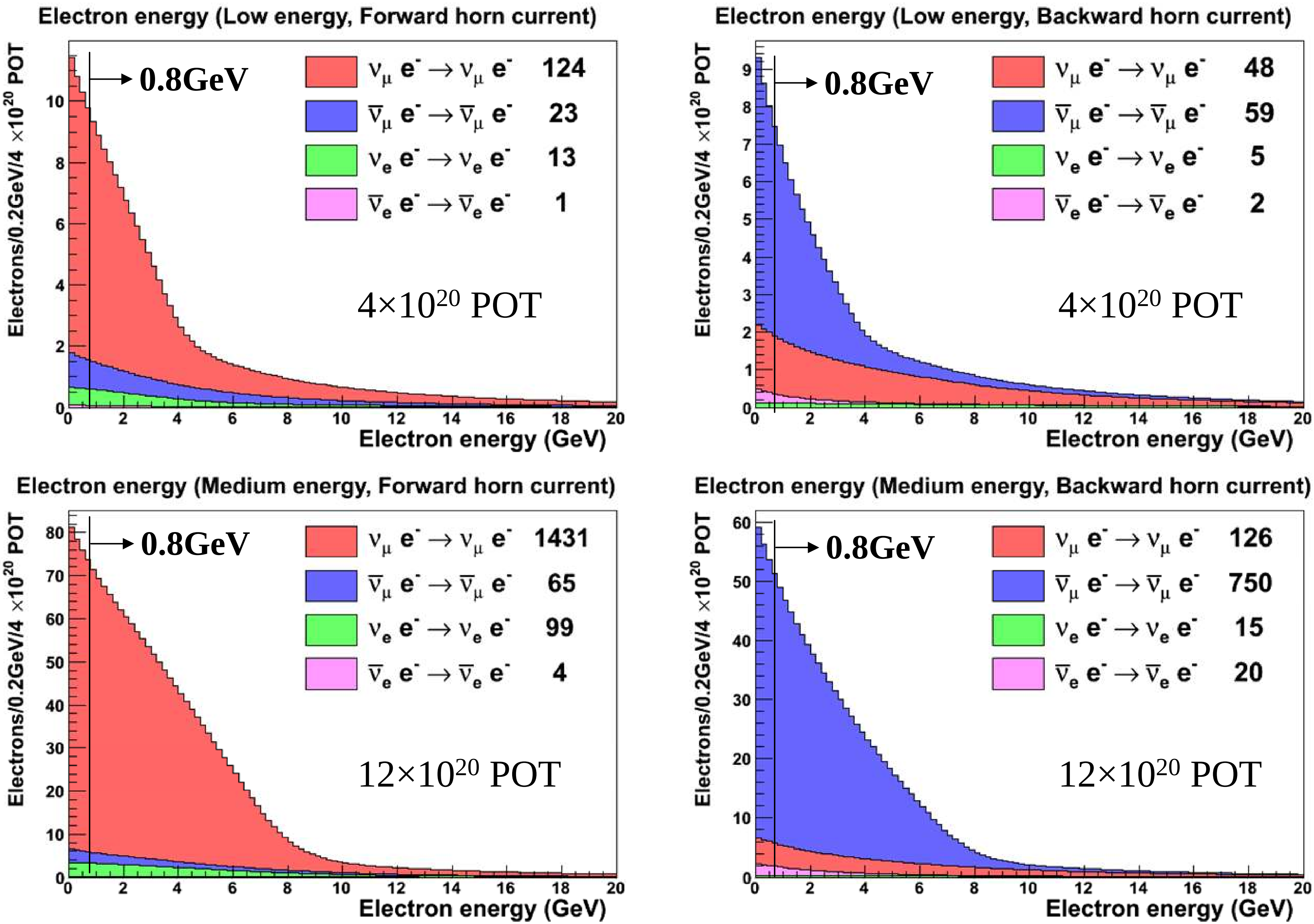
Medium energy, Forward horn current flux



Medium energy backward horn current flux



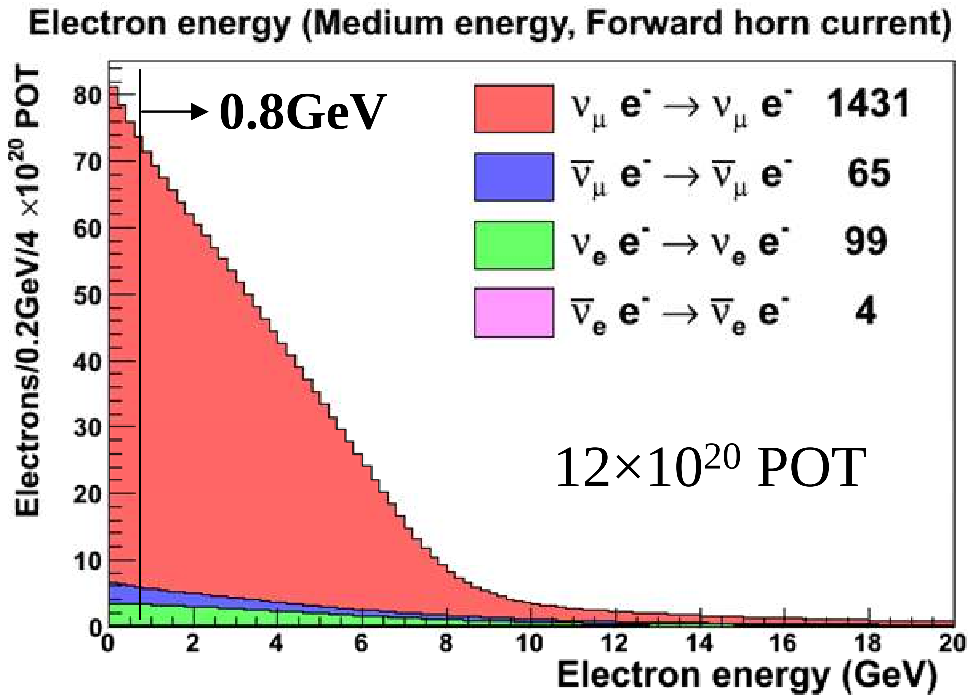
Electron Spectrum



What do we expect in ME?

- Medium energy beam shows ~10 times statistics compared to low energy beam
  - Assuming:
    - low energy: 4E20 POT
    - medium energy: 12E20 POT
- It's based on old histogram flux file (docdb-2004)
  - Laura mentioned that this flux is old and current LE flux has 20~30% higher than one I'm using
  - Because the increase is due to hadron production module, ME flux will crease in similar way
- If we assume we have similar fraction of background as low energy beam:
  - Signal/Background =173/47 (LE)
  - Signal/Background = 1730/470 (ME, scaled from LE)
  - Statistical error = ~2.7%

How Do We Get Flux from Electron Spectrum?



Flux?

$$h(E_e) = \int \underline{f(E_\nu)}\,\underline{g(E_\nu, E_e)}\,dE_\nu$$

Electron spectrum **Flux** **Differential cross section**

- From flux, electron spectrum is deterministic
- If we have high statistics, we should be able to calculate flux from the electron spectrum
- In practice, it’s harder
- Actual data will have energy smearing and background

Skewed Contribution

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^- \quad \textbf{only}$$

- 0-1 GeV electron gets contribution from whole neutrino energy
- 12-13 GeV electron gets contribution from neutrino > 12 GeV